Contents

PART A

Preface vii
Opening Address ix

Section 1. Invited Papers

History, present status and future of fusion reactor materials research in Japan, *S. Ishino, T. Kondo and M. Okada* 3
A perspective on the history, status and future of fusion materials research in the United States, *T.C. Reuther* 9
History, present status and future of fusion reactor materials research in the EC and other European countries, *P. Schiller, K. Ehrlich and J. Nihoul* 13
Thermal effects and other critical issues of plasma-facing components, *A. Miyahara and J.B. Whitley* ... 19
Radiation enhanced sublimation of carbon and carbon related materials, *V. Philipps, E. Vietzke and H. Trinkaus* 25
Sputtering of low-Z materials, *J. Roth, W. Eckstein, E. Gauthier and J. Laszlo* 34
Radiation damage and irradiation effects in solid breeders, *K. Noda* 37
Research and development status of ceramic breeder materials, *C.E. Johnson* 42
Research and development on liquid Pb-17Li breeder in Europe, *G. Casini and J. Sannier* 47
Characteristics of microstructural evolution of radiation damage in ceramics under fusion environment, *C. Kinoshita* 53
Dielectric and electrical design consideration of ceramics for fusion devices, *H. Ohno* 60
Design parameters of ceramic insulator materials for fusion reactors, *R. Heidinger* 64
Effects of the primary recoil spectrum on microstructural evolution, *H. Wiedersich* 70
Phase stability and cascade size, *H. Wollenberger* 76
Recoil energy spectrum effects and point defect processes characteristic of cascades, *M. Kiritani* ... 81
Molecular dynamics studies of displacement cascades, *R.S. Averback, H. Hsieh, T. Diaz de la Rubia and R. Benedek* 87
Computer simulation of cascade damage in metals, *Y. Yamamura* 94
Theory of microstructure evolution under fusion neutron irradiation, *N.M. Ghoniem* 99
Theoretical basis for unified analysis of experimental data and design of swelling-resistant alloys, *L.K. Mansur and E.H. Lee* 105
New developments in fusion materials research using surrogate neutron spectra, *F.A. Garner* 111
Helium and hydrogen effects on the embrittlement of iron- and nickel-based alloys, *H. Schroeder and H. Ullmaier* 118
Radiation effects at fusion reactor He : dpa ratios: Overview of US/Japan spectrally tailored experiments, *A.F. Rowcliffe, A. Hishinuma, M.L. Grossbeck and S. Jitsukawa* 125
Low-temperature irradiation creep of fusion reactor structural materials, *M.L. Grossbeck and L.K. Mansur* 130
Objectives and prospects for low-activation materials, *G.J. Butterworth* 135
A proposal to alloy design for low activation high manganese austenitic stainless steel – Role of carbon and nitrogen, *Y. Hosoi* 143
Evaluation of low-activation vanadium alloys for use as structural material in fusion reactors, *B.A. Loomis, A.B. Hull and D.L. Smith* 148

Discussion on Invited Papers 157

CONTRIBUTED PAPERS (Sections 2–8)

Section 2. Plasma-facing Components

2.1. Graphite and C–C composites

Brazed graphite/refractory metal composites for first-wall protection elements, *I. Šmid, C.D. Croessmann, J.C. Salmonson, J.B. Whitley, E. Kny, N. Reheis, G. Kneringer and H. Nickel* 169
Design optimization study of an innovative concept of divertor plate based on fibre composite technology, *R. Matera, W. Janssens, Y. Crutzen, F. Farfaletti-Casali and P. De Meester* 173
Thermal erosion of graphite by pulsed electron beam, *S. Nishikawa, M. Sawada, Y. Marukawa, P. Son and M. Miyake* 176
Study of Raman spectroscopy on carbon materials irradiated with a high current density electron beam, *M. Kitajima, K. Nakamura, M. Fujitsuka, H. Shinno, T. Tanabe and M. Yumoto* 180
Simulation and analysis of the response of carbon materials to off-normal heat loads accompanying plasma disruptions, *J.G. Van der Laan and H.T. Klippel* 184
Thermal shock experiments for carbon materials by electron beams, *M. Fujitsuka, H. Shinno, T. Tanabe and H. Shiraishi* 189
Pulse high heat flux experiment with laser beams on graphite, *H. Kamezaki, K. Tokunaga, S. Fukuda, N. Yoshida and T. Muroga* 193
Development of carbon composite property requirements for high heat flux components, *J.W. Davis, D.A. Bowers, F.R. Williams and J.R. Haines* 197

Positron annihilation study of irradiation effects on graphites, *E. Kuramoto, M. Takenaka, M. Hasegawa and T. Tanabe* 202
The effects of radiation damage on the properties of GraphNOL N3M, *T.D. Burchell and W.P. Eatherly* 205
Induced radioactivity of commercial isotropic graphites for high heat flux tiles, *T. Shikama, H. Kayano, M. Fujitsuka and T. Tanabe* 209
Laser Raman microprobe analysis of the modified surface of He^+-irradiated graphite, *K. Niwase, K. Nakamura, I. Tanaka, Y. Miyamoto and T. Tanabe* . 214
Modification of graphite structure by D^+ and He^+ bombardment – II, *K. Niwase and T. Tanabe* 218
Solubility of hydrogen isotopes in graphite, *Y. Shirasu, S. Yamanaka and M. Miyake* 223
Dissolution and diffusion of helium in graphite, *H. Atsumi, T. Yamauchi and M. Miyake* 227
Hydrogen behavior in graphite at elevated temperatures, *T. Tanabe and Y. Watanabe* 231
Tritium diffusion in pseudo-monocrystal graphite, observed with a tritium imaging camera, *K.N. Kushita, I. Youle, A.A. Haasz and J.A. Sawicki* 235
Dependence of hydrogen permeabilities of isotropic graphites on the pore structure, *M. Yamawaki, K. Yamaguchi, Y. Suzuki and S. Tanaka* 239
Effect of coatings on the hydrogen permeability of graphite, *K. Yamaguchi, Y. Suzuki, S. Tanaka and M. Yamawaki* 242

2.2. Non-graphite composites

Effects of He^+ irradiation on the mechanical properties of molybdenum, *K. Shinohara, A. Kawakami, S. Kitajima, Y. Nakamura and M. Kutsuwada* 246
Neutron-induced changes in density and electrical conductivity of copper alloys at 16 to 98 dpa and 430 °C, *F.A. Garner, H.R. Brager and K.R. Anderson* 250
Effects of neutron irradiation on metal matrix composites, *A. Kohyama, S. Sato, H. Tezuka and M. Kondo* 254
Microstructure, microchemistry and strength of insulating ceramics joined to a fusion candidate austenitic steel by diffusion bonding, *T. Muroga, Y. Aono, N. Yoshida, Y. Murata and Y. Fukuzawa* 259
Strength and fatigue of dispersion-strengthened copper, *T.J. Miller, S.J. Zinkle and B.A. Chin* 263
Magnetic particles induced by plasma disruptions in tokamaks, *E. Franconi* 267
Structural and metallurgical effects in stainless steel for first-wall applications in simulated plasma disruptions, *J.G. Van der Laan, H.T. Klippel, J. Bakker and R.C.L. Van der Stad* 270
Application of tungsten single crystals for fusion reactors, *Y. Hiraoka, M. Fujitsuka and T. Fujii* 275
Cavity formation by thermal treatment in ODS steel, *N. Igata, T. Nagato and H. Yumoto* 279
Response of stainless steels to plasma disruptions by simulation experiments with an intense hydrogen beam, *K. Kiuchi, M. Kikuchi, H. Bolt, M. Araki and M. Seki* 282
Protection against arc erosion of 316 stainless steel by plasma source nitridation, *M. Nunogaki, S. Ooi and K. Miyazaki* 286
Sputtering of tungsten by oxygen at temperatures up to 1900 K, *E. Hechtl, W. Eckstein, J. Roth and J. Laszlo* 290

2.3. Plasma-facing components related to specific tokamak machines

Sputtering of TiC coating by low-energy and high flux plasma bombardment in PISCES, *E. Franconi and F. Brossa* 294
Topographical change of high-temperature copper surface bombarded by Ar ions, *Y. Takao, Y. Kanda, T. Yomura, A. Hashiguchi and S. Kurisu* 298
Poisoning effect on solubility of hydrogen isotopes in getter materials, *S. Yamanaka, Y. Sato, H. Ogawa, Y. Shirasu and M. Miyake* 303
Thermal release behavior of helium implanted into nickel, *T. Yamauchi, S. Yamanaka and M. Miyake* . 308
Tritium release behavior of a Al–Mg–Li alloy irradiated by thermal neutrons, *M. Sugisaki, H. Furuya, T. Ichigi, N. Koori and I. Kumabe* 312
Recycling of hydrogen from stainless steel surfaces under ITER/NET conditions, *F. Reiter, J. Camposilvan, M. Caorlin, A. Perujo and S. Tominetti* 316
In-situ depth-profiling of deuterium in nickel exposed to RF plasma, *I. Takagi, M. Matsuoka, H. Fujita, K. Shin and K. Higashi* 319
The behavior of diffusion and permeation of tritium through 316L stainless steel, *S. Changqi, W. Aiju and C. Qingwang* 322
The modeling of hydrogen transport in metals and its application to the evaluation of hydrogen permeation and inventories, *K. Yamaguchi, S. Tanaka and M. Yamawaki* 325
Tritium release from irradiated beryllium at elevated temperatures, *D.L. Baldwin, O.D. Slagle and D.S. Gelles* 329
Permeation of deuterium implanted into copper, *T. Nagasaki, R. Yamada and H. Ohno* 335
Performance of JT-60 divertor plates, *T. Ando, H. Takatsu, H. Nakamura, M. Yamamoto, K. Kodama, T. Arai, M. Shimizu, K. Fukaya, M. Eto and T. Oku* 339
Electron beam heating tests of newly-developed C/C composites for application to JT-60U divertor plate, *H. Takatsu, M. Seki, M. Araki, M. Yamamoto, K. Fukaya, M. Ogawa, M. Etoh, S. Yamazaki, S. Koga and T. Kobayashi* 344
Study on hydrogen-isotope retention with collector probes in JFT-2M scrape-off layer, *T. Nakajima, I. Takaya, T. Akiyama, A. Kitamura, S. Yano, S. Sengoku, H. Ohtsuka and H. Maeda* 349
Modification of a limiter under ultra long pulse operation in the superconducting high-field tokamak TRIAM-1M, *K. Tokunaga, T. Fujiwara, N. Yoshida, T. Muroga, S. Itoh and The TRIAM Group* 353
Electron microscopy of materials modification induced by tokamak plasma, *K. Tokunaga, T. Muroga, Y. Miyamoto, T. Fujiwara, N. Yoshida, K. Nakamura, N. Hiraki, S. Itoh and The TRIAM Group* 356

Evaluation of runaway-electron effects on plasma-facing components for NET, *H. Bolt and H. Calén* ... 360

Section 3. Ceramic Materials

3.1. Materials development

Influence of thermal shocks on the strength of silicon carbide, *A. Brandstädter, K. Koizlik, J. Linke, H. Schiffers, E. Wallura and H. Nickel* 367
Plasma-sprayed titanium carbide coatings for first-wall applications in fusion devices, *P. Groot, J.G. Van der Laan, M. Mack, M. Dvorak and P. Huber* . 370
The effect of ZrO_2 doping on mechanical and dielectric properties of Al_2O_3 and $MgAl_2O_4$, *J. Mollá, A. Ibarra, H.M. Frost, III, F.W. Clinard, Jr., J.C. Kennedy, III and M. Jiménez de Castro* 375
Carbon fiber/SiC composite for reduced activation, *T. Noda, H. Araki, F. Abe and M. Okada* 379

3.2. Radiation effects on properties

Radiation-enhanced electrical breakdown in fusion insulators, *E.R. Hodgson* 383
Thermal and mechanical properties of neutron-irradiated aluminum nitride, *T. Yano and T. Iseki* 387
Damage to Macor glass-ceramic from high-dose 14 MeV neutrons, *W.A. Coghlan and F.W. Clinard, Jr.* 391

3.3. Radiation effects on structures

Helium-assisted cavity formation in ion-irradiated ceramics, *S.J. Zinkle and S. Kojima* 395
Kinetic study of defect clusters in the $MgO–Al_2O_3$ system under electron- and/or ion-irradiation, *Y. Satoh, C. Kinoshita and K. Nakai* 399
Damage structure obtained by cross-sectional observation in silicon carbide irradiated with helium ions, *K. Nakata, S. Kasahara, S. Shimanuki, Y. Katano, H. Ohno and J. Kuniya* 403
Helium release and microstructure of neutron-irradiated SiC ceramics, *K. Sasaki, T. Yano, T. Maruyama and T. Iseki* 407
New in-situ parallel-detection electron energy-loss spectroscopy of SiC crystals irradiated with hydrogen ions, *K. Hojou, S. Furuno, T. Soga and K. Izui* 411

Section 4. Structural Materials

4.1. Miniaturized specimen techniques

Specimen size effects on tensile properties of neutron-irradiated steels, *A. Kohyama, K. Hamada and H. Matsui* 417
Determination of the minimum quantity of irradiated ferritic steel specimens for small punch DBTT testing, *T. Misawa, K. Suzuki, M. Saito and Y. Hamaguchi* 421
Charpy impact testing using miniature specimens and its application to the study of irradiation behavior of low-activation ferritic steels, *H. Kayano, H. Kurishita, A. Kimura, M. Narui, M. Yamazaki and Y. Suzuki* 425
Application of ball punch tests to evaluating fracture mode transition in ferritic steels, *J. McNaney, G.E. Lucas and G.R. Odette* 429
Development of disc compact tension specimens and test techniques for HFIR irradiations, *C. Elliott, M. Enmark, G.E. Lucas, G.R. Odette and A. Rowcliffe* . 434
Development of miniature bending fatigue specimens, *G.R. Rao, A. Rowcliffe and B.A. Chin* 438
Evaluation of toughness degradation by small punch (SP) tests for neutron-irradiated $2\frac{1}{4}$Cr–1Mo steel, *M. Suzuki, M. Eto, K. Fukaya, Y. Nishiyama, T. Kodaira, T. Oku, M. Adachi, A. Umino, I. Takahashi, T. Misawa and Y. Hamaguchi* 441
Microbulge testing applied to neutron irradiated materials, *A. Okada, M.L. Hamilton and F.A. Garner* 445

4.2. Radiation effects on microstructure

Correlation between hydrogen and helium retentions in stainless steel irradiated with helium and hydrogen, *M. Ogawa, M. Nakajima, K. Kurimoto and K. Hashimoto* 449
Helium bubble microstructure in SS 316L, 20% c.w. and its correlation to the in-beam mechanical properties, *H. Schroeder and N. Yamamoto* 453
Radiation-induced amorphization and swelling in ceramics, *A. Matsunaga, C. Kinoshita, K. Nakai and Y. Tomokiyo* 457
Neutron irradiation damage in transition metal carbides, *H. Matsui, K. Nesaki and M. Kiritani* 461
Structural changes of deposited $Ti_{1-x}B_x$ films due to neutron irradiation, *T. Shikama and H. Kayano* ... 465
Helium irradiation effects on structural properties of AlN thin films, *N. Kobayashi, H. Kobayashi, I. Sakamoto and N. Hayashi* 469
Neutron irradiation effects of $PbO–SiO_2$ glasses, *H. Ohno, T. Nagasaki, N. Igawa and H. Kawamura* ... 473

4.3. Property and materials design

Alloy development for first wall materials used in water-cooling type fusion reactors, *K. Kiuchi, T. Ishiyama and A. Hishinuma* 477
A new type of low temperature sensitization of austenitic stainless steels enhanced with defect–solute interactions, *K. Kiuchi, M. Kikuchi and T. Kondo* 481
Behaviour of first-wall components under thermal fatigue, *R. Matera, M. Merola, M. Biggio, E. Cicchetti, V. Renda and M. Eto* 485
High-temperature thermal fatigue of AISI 316L steel, *C. Petersen and G.H. Rubiolo* 488
Effect of the δ-ferrite phase on the impact properties of martensitic chromium steels, *K. Anderko, L. Schäfer and E. Materna-Morris* 492
Application of electron energy loss spectroscopy to microchemical analysis of Ti-modified austenitic stainless steel irradiated in HFIR, *K. Hojou, S. Jitsukawa, M. Suzuki, S. Hamada and A. Hishinuma* 496
Effect of additional elements on cavity formation near grain boundary in proton-irradiated austenitic stainless steels, *S. Kasahara, K. Nakata, H. Takahashi, S. Ohnuki and J. Kuniya* 500

Influence of minor elements on the dimensional stability of austenitic stainless steels under proton irradiation, *P. Jung and H. Klein* ... 503
Compositional dependence of dislocation loop development and microstructures in austenitic Fe–Ni–Cr alloys under proton irradiation, *T. Kimoto, K. Furuya and H. Shiraishi* ... 507
Synergistic effects of helium and other variables on microstructure change in neutron-irradiated Fe–Ni–Cr alloys doped with ^{59}Ni, *H. Kawanishi, F.A. Garner and R.L. Simons* ... 511
Microstructural evolution in austenitic stainless steels irradiated to 57 dpa in HFIR, *S. Hamada, M. Suzuki, P.J. Maziasz and A. Hishinuma* ... 515
Microstructural evolution of welded austenitic stainless steels irradiated in the spectrally-tailored ORR experiment at 400°C, *T. Sawai, P.J. Maziasz and A. Hishinuma* ... 519
The relative influence of helium/dpa ratio and other variables on neutron-induced swelling of Fe–Ni–Cr alloys at 495°C and 14 dpa, *J.F. Stubbins and F.A. Garner* ... 523
Electron irradiation damage in austenitic stainless steels, *S. Jiguang, Q. Jiapu, Z. Zhuoyong, C. Jiming and X. Zengyu* ... 526
Effect of combined addition of phosphorus and titanium on microstructural evolution in Fe–Cr–Ni alloys, *H. Watanabe, A. Aoki, T. Muroga and N. Yoshida* ... 529
Characterization of microstructure at 673 K in neutron-irradiated Fe–16Ni–15Cr with the addition of C, Ti and Nb, *H. Kawanishi and S. Ishino* ... 534
Effect of phosphorus and boron additions on helium bubble microstructure in titanium-modified austenitic stainless steels, *S. Jitsukawa, K. Hojou and A. Hishinuma* ... 538
The effect of titanium addition on microstructural evolution in austenitic steel irradiated with fast neutrons in FFTF, *N. Sekimura and S. Ishino* ... 542
Microstructural investigation of swelling dependence on nickel content in fast neutron-irradiated Fe–Cr–Ni austenitic ternaries, *T. Muroga, F.A. Garner and S. Ohnuki* ... 546
Damage profiles in a stainless steel irradiated with Ar and N ions, *K. Shiraishi, K. Fukai and E. Yagi* ... 550

4.4. Radiation effects on mechanical properties

Isotopic tailoring with ^{59}Ni to study the influence of helium/dpa ratio on tensile property changes, *F.A. Garner, M.L. Hamilton, R.L. Simons and M.K. Maxon* ... 554
Tensile behavior and swelling of ternary austenitic alloys irradiated in different neutron spectra, *M.L. Hamilton, A. Okada and F.A. Garner* ... 558
Stress–strain relations of HFIR-irradiated austenitic stainless steels, *S. Jitsukawa, M.L. Grossbeck and A. Hishinuma* ... 563
Empirical relations for tensile properties of austenitic stainless steels irradiated in mixed-spectrum reactors, *M.L. Grossbeck* ... 568
The effects of intermediate temperature irradiation on the mechanical behavior of 300-series austenitic stainless steels, *G.R. Odette and G.E. Lucas* ... 572
Irradiation creep and swelling of the fusion heats of PCA, HT9 and 9Cr–1Mo irradiated to high neutron fluence, *F.A. Garner and R.J. Puigh* ... 577
Irradiation creep and swelling of annealed Type 304L stainless steel at ~ 390°C and high neutron fluence, *D.L. Porter, G.D. Hudman and F.A. Garner* ... 581
Effects of in-situ pulse irradiation of 20 MeV protons and thermal pulses on the fatigue properties of low-carbon 316 stainless steel, *H. Mizubayashi, C. Yan, H. Kikuchi, S. Okuda and Y. Tagishi* ... 585
Effects of neutron irradiation on strength of fusion reactor materials and their electron beam welded joints, *S. Kaga, T. Tamura, H. Yoshida and K. Miyata* ... 588
Mechanical properties and neutron-irradiation effects in the welds of molybdenum and its alloys, *F. Morito and K. Shiraishi* ... 592

4.5. Environmental effects

Recent results on corrosion behaviour of MANET structural steel in flowing Pb–17Li eutectic, *H.U. Borgstedt and H.D. Röhrig* ... 596
Corrosion of Type 316L stainless steel in Pb–17Li, *M.G. Barker, J.A. Lees, T. Sample and P. Hubberstey* ... 599
Corrosion of austenitic stainless steel in liquid lithium, *J. Qian, J. Chen, J. Chen, Z. Xu, W. Wang and C. Pan* ... 603
Stress-corrosion cracking issues related to a water-cooled ITER, *R.H. Jones, S.M. Bruemmer and C.H. Henager, Jr.* ... 607
Comparison of stress corrosion cracking susceptibility of austenitic and ferritic stainless steels in small punch testing, *T. Misawa, T. Ohtsuka, M. Seo and M. Saito* ... 611
An investigation of the sensitization behavior of Fe–Mn–Cr austenitic steels, *G.E.C. Bell, P.F. Tortorelli, E.A. Kenik and R.L. Klueh* ... 615
Electrochemical evaluation of sensitization in austenitic stainless steels using miniaturized specimens, *T. Inazumi, G.E.C. Bell and K. Kiuchi* ... 619

4.6. Low-activation austenitic steels

The effect of solute content on grain boundary segregation in electron-irradiated Fe–Cr–Mn alloys, *T. Kato, H. Takahashi, S. Ohnuki, K. Nakata and J. Kuniya* ... 623
Phase evolution during neutron irradiation of commercial Fe–Cr–Mn alloys, *J.M. McCarthy* ... 626
Effect of alloying elements on phase stability in neutron-irradiated Fe–Cr–Mn model alloys, *H. Takahashi, S. Ohnuki, H. Kinoshita and S. Nakahigashi* 629
Neutron-induced swelling of model Fe–Cr–Mn–Ni alloys and commercial manganese-stabilized steels, *F.A. Garner, H.R. Brager and H. Takahashi* ... 633
Mechanical characteristics and swelling of austenitic Fe–Cr–Mn steels irradiated in the SM-2 and BOR-60 reactors, *V.K. Shamardin, T.M. Bulanova, V.S. Neustroev, L.I. Ivanov, E.V. Djomina and Y.M. Platov* ... 637

Irradiation effects on mechanical properties of low activation Mn–Si–Cr steels, *H. Yoshida, K. Miyata, S. Nishikawa and H. Kodaka* 640
Fracture behavior of neutron-irradiated high-manganese austenitic steels, *H. Yoshida, K. Miyata, M. Narui and H. Kayano* 644
Formation of dislocations, precipitates and cavities in He-implanted Mn–Cr austenitic steels, *E. Ruedl and G. Valdrè* 648
Microstructure and mechanical properties of α-particle irradiated Cr–Mn and the other stainless steels, *K. Miyahara, Y. Sakamoto, S. Hamada, H. Kayano and Y. Hosoi* 652
Decrease of ductility due to hydrogen in Fe–Cr–Mn austenitic steel, *N. Igata, T. Fujiga and H. Yumoto* . 656

4.7. Low-activation ferritic steels

The mechanical behaviour of newly designed low-activation high-chromium martensitic steels, *E. Dequidt, J. Arroyo and M. Schirra* 659
Alloy composition selection for improving strength and toughness of reduced activation 9Cr–W steels, *F. Abe, T. Noda, H. Araki and S. Nakazawa* 663
Effects of W and Mn on the mechanical properties, microstructure and aging behaviors of 10% Cr ferritic steels considered as reduced radio-activation materials, *K. Miyahara, Y. Kobayashi and Y. Hosoi* 667
Effects of small changes in alloy composition on the mechanical properties of low activation 9%Cr–2%W steel, *H. Kayano, A. Kimura, M. Narui, T. Kikuchi and S. Ohta* 671
Internal strains after recovery of hardness in tempered martensitic steels for fusion reactors, *L. Brunelli, P. Gondi, R. Montanari and R. Coppola* 675
Heat-treatment effect on impact properties of reduced-activation steels, *R.L. Klueh, P.J. Maziasz and D.J. Alexander* 679
The effect of ageing on the properties and structures of low activation martensitic 9 and 11% Cr, W, V stainless steels, *K.W. Tupholme, D. Dulieu and G.J. Butterworth* 684
Effect of thermo-mechanical treatment on toughness of 9Cr–W ferritic–martensitic steels during aging, *S. Kunimitsu, Y. You, N. Kasuya, Y. Sasaki and Y. Hosoi* 689
Mechanical properties of welded joints of the reduced-activation ferritic steel: 8% Cr–2% W–0.2% V–0.04% Ta–Fe, *H. Hayakawa, A. Yoshitake, M. Tamura, S. Natsume, A. Gotoh and A. Hishinuma* 693
The tensile and fatigue properties of Type 1.4914 ferritic steel for fusion reactor applications, *P. Marmy, R. Yuzhen and M. Victoria* 697
Neutron damage in reduced activation martensitic alloys in inertial and magnetic fusion reactors: Comparison with fission reactors, *J. Sanz and J.M. Perlado* 702
Microstructural investigation of 12% Cr martensitic steel for NET by means of small angle neutron scattering, *G. Albertini, F. Carsughi, R. Coppola, F. Rustichelli, W.A.H.M. Vlak and C. Van Dijk* 706
Microstructural developments in Fe–Cr–W low activation ferritic steels under dual beam charged particle irradiation, *S. Hiwatashi, Y. Kohno, K. Asakura and A. Kohyama* 709
Phase stability of a manganese-stabilized low-activation martensitic steel, *R.D. Griffin, D.S. Gelles, R.A. Dodd and G.L. Kulcinski* 714
Microstructural development of 10Cr–2Mo ferritic steel irradiated to 57 dpa in HFIR, *M. Suzuki, T. Sawai, P.J. Maziasz and A. Hishinuma* 718
Development of damage structure in oxide dispersion strengthened steels, *H. Kinoshita, N. Akasaka, H. Takahashi, M. Itoh and S. Onose* 722
Microstructural examination of FFTF-irradiated manganese-stabilized martensitic stainless steel, *Y. Kohno, A. Kohyama and D.S. Gelles* 725
Irradiation hardening of ferritic steels: Effect of composition, *R.L. Klueh* 728
Impact behavior of 9Cr–1MoVNb and 12Cr–1MoVW steels irradiated in HFIR, *R.L. Klueh and D.J. Alexander* 733
Effects of neutron irradiation on hydrogen-induced intergranular fracture in a low activation 9%Cr–2%W steel, *A. Kimura, H. Kayano and M. Narui* 737
Irradiation-induced suppression of creep in a low activation 9%Cr-2%W steel, *A. Kimura, H. Kayano and S. Ohta* 741
Investigations on creep and microstructure in proton-irradiated DIN 1.4914 martensitic stainless steel, *P. Jung* 745
Low temperature embritllement of low energy He implanted pure iron and iron-based alloys, *Y. Nakamura, S. Kitajima, K. Shinohara, S. Ishimoto, T. Shodai, T. Torimaru and K. Yasuda* 749
Low-cycle fatique properties of the helium-implanted 12% Cr steel 1.4914 (MANET), *R. Lindau and A. Möslang* 753

4.8. Low-activation vanadium and other alloys

High-temperature deformation of modified V–Ti–Cr–Si type alloys, *M. Satou, K. Abe and H. Kayano* 757
Compatibility of a V–15Cr–5Ti alloy with SiC at high temperatures, *K. Kurokawa, K.-y. Aota and H. Takahashi* 762
Solid-state bonding between vanadium alloys and alumina, *K. Abe, T. Higuchi and Y. Fujino* 766
Swelling of neutron-irradiated vanadium alloys, *B.A. Loomis, D.L. Smith and F.A. Garner* 771
Microstructural examination of simple vanadium alloys irradiated in the FFTF/MOTA, *S. Ohnuki, D.S. Gelles, B.A. Loomis, F.A. Garner and H. Takahashi* . 775
Hydrogen embrittlement of MFR candidate vanadium alloys, *S. Yano, M. Tada and H. Matsui* 779
Response of unirradiated and neutron-irradiated vanadium alloys to Charpy-impact loading, *B.A. Loomis and D.L. Smith* 783
Helium production and precipitates in neutron-irradiated Al–Li and Al–Mg–Li alloys, *I. Yoshizawa, Y. Katano, K. Kamada and H. Ohno* 787

PART B

Section 5. Breeding Materials

5.1. Fabrication and properties

Process for the preparation of lithium metazirconate, *D. Vollath and H. Wedemeyer* 793
Research and development work for the lithium orthosilicate pebbles for the Karlsruhe ceramic breeder blanket, *M. Dalle Donne, E. Günther, G. Schumacher, G. Sordon, D. Vollath, H. Wedemeyer and H. Werle* 796
Interaction of tritium gas with Li_2O crystals and dissolution processes, *H. Kudo, S. O'hira, M. Fujie and K. Noda* 800
Thermochemical study of vaporization of ceramic breeding materials by Knudsen effusion mass spectrometry, *M. Yamawaki, K. Yamaguchi and M. Yasumoto* 804
Equilibrium pressure of water vapor over a Li_2O(s)–LiOH(s, l) mixture, *T. Terai, H. Mohri and Y. Takahashi* 808
Desorption of H_2O and H_2 from steel and $LiAlO_2$ by temperature programmed desorption, *A.K. Fischer and C.E. Johnson* 812
Enhanced tritium transport and release by solids modification, *J.P. Kopasz, S.W. Tam and C.E. Johnson* 816
Compatibility problems in tritium breeding blankets, *M. Broc, T. Flament, A. Terlain and J. Sannier* 820
Compatibility between vanadium-base alloys and flowing lithium: Partitioning of hydrogen at elevated temperatures, *A.B. Hull, O.K. Chopra, B. Loomis and D. Smith* 824
The Sibelius experiment: Study of the irradiation behaviour of beryllium/ceramic and beryllium/steel compacts, *N. Roux, M. Briec, M. Bruet, T. Flament, C. Johnson, M. Masson, A. Terlain and F. Tournebize* 827

5.2. Irradiation and tritium release

Comparative irradiation of different lithium ceramics, *K.R. Kummerer and H.-J. Ritzhaupt-Kleissl* 831
Electrical conductivity of Li_2O under and after irradiation, *K. Noda, Y. Ishii, H. Matsui, H. Ohno and H. Watanabe* 835
The interactions of tritium with irradiation defects in solid breeder materials, *H. Moriyama, A. Okada, Y. Asaoka and Y. Ito* 839
The FUBR-1B irradiation experiment – Tritium release and physical stability of solid breeder materials, *O.D. Slagle, G.W. Hollenberg and D.L. Baldwin* ... 843
Experimental evidence for tritium release-controlling processes in lithium silicates, *W. Breitung and H. Werle* 847
The influence of surface phenomena on in-situ tritium release from lithium oxide, *T. Kurasawa and H. Watanabe* 851
Bubble formation in irradiated Li_2O, *R.A. Verrall, D.H. Rose, J.M. Miller, I.J. Hastings and D.S. MacDonald* 855
Investigations of hydrogen/Li_2O surface interactions via quantum chemical cluster methods, *S.W. Tam, J. Wright, L.A. Curtiss and C.E. Johnson* 859
Storage of tritium in ZrCo alloy: Effect of pre-exposure to impurities relevant to the fusion fuel cycle, *R.-D. Penzhorn, M. Devillers and M. Sirch* 863
In situ tritium release experiments from solid breeding materials (TTTEx) – Surface reaction on Li_2O and $LiAlO_2$ for sweep gases of $He + H_2$ and $He + H_2O$, *S. Tanaka, A. Kawamoto, D. Yamaki, K. Yamaguchi and M. Yamawaki* 867
In-reactor tritium release experiment from molten lithium–lead alloy ($Li_{17}Pb_{83}$), *T. Terai, S. Nagai and Y. Takahashi* 871
Irradiation of liquid breeder material Pb–17Li with in-situ tritium release measurements in the LIBRETTO 2 experiment, *R. Conrad, L. Debarberis, V. Coen and T. Flament* 875

5.3. Liquid breeder

Equilibrium distributions of tritium in liquid lithium/molten salt systems, *Y. Asaoka, H. Moriyama and Y. Ito* 879
Transport of deuterium and rare gases by flowing molten Pb–17Li, *H. Feuerstein, H. Gräbner, S. Horn and J. Oschinski* 882
Continuous monitoring of the composition of liquid Pb–17Li eutectic using electrical resistivity methods, *P. Hubberstey, T. Sample and M.G. Barker* 886

Section 6. Radiation Damage

6.1. Primary damage and collision cascades

The morphology of collision cascades as a function of recoil energy, *H.L. Heinisch and B.N. Singh* 893
Time development of cascades by the binary collision approximation code, *A. Fukumura, N. Sekimura and S. Ishino* 897
Criterion of subcascade formation in metals from atomic collision calculation, *Y. Satoh, S. Kojima, T. Yoshiie and M. Kiritani* 901
Computer simulation of displacement cascade structures in D–T neutron-irradiated Au, Ag, Cu, Ni and Al with the MARLOWE code, *N. Watanabe, R. Nishiguchi and Y. Shimomura* 905
The effects of many-body interactions on point-defect generation, *S.P. Chou and N.M. Ghoniem* 909
Analysis of the sub-cascade structure in copper produced by ion irradiations, *I. Ishida, S. Sasaki, T. Yoshiie, A. Iwase, T. Iwata and M. Kiritani* 913
Accumulation process of cascades in ceramics under ion and/or electron irradiation, *H. Abe, C. Kinoshita and K. Nakai* 917
Disorder-induced amorphization of intermetallic compounds: A molecular dynamics study, *C. Massobrio, V. Pontikis, N.V. Doan and G. Martin* 921

6.2. Point defect clusters from cascades

Defect structures in copper and gold irradiated with fast neutrons, 14 MeV neutrons and 600–800 MeV pro-

tons, *A. Horsewell, B.N. Singh, S. Proennecke, W.F. Sommer and H.L. Heinisch* 924
In-situ observation of cascade damage in nickel and copper under heavy ion irradiation, *H. Sakaida, N. Sekimura and S. Ishino* 928
Positron lifetime measurement and latent vacancy clusters in 14 MeV neutron irradiated nickel, *T. Yoshiie, M. Hasegawa, S. Kojima, K. Sato, Y. Saitoh, S. Yamaguchi and M. Kiritani* 931
Structure and kinetics of cascades in copper under ion and/or electron irradiation, *K. Fukumoto, C. Kinoshita, H. Abe, K. Shinohara and M. Kutsuwada* . 935
On the nature of TEM-observed defect clusters in low-dose neutron- and ion-irradiated Cu, Ag and Au at room temperature, *H. Fukushima, Y. Shimomura and H. Yoshida* 939
Annealing experiments of low temperature 14 MeV neutron-irradiated ordered and disordered Cu_3Au by TEM, *H. Fukushima, Y. Shimomura, M.W. Guinan, P.A. Hahn and M. Kiritani* 943
Defects in Si irradiated with D–T neutrons, D and He ions, *R. Oshima, S. Honda, G.C. Hua, T. Tanabe and F.E. Fujita* 947

6.3. Point defect processes and microstructure evolution

Diffusion-based evaluation of defect processes in cascade zones, *C.H. Woo, B.N. Singh and H.L. Heinisch* 951
Effect of cascade localization induced bias on defect structure evolution, *T. Yoshiie, Y. Satoh, S. Kojima and M. Kiritani* 954
Determination of sink concentrations in ion irradiated nickel and copper by diffusion measurements, *A. Müller, M.-P. Macht and V. Naundorf* 958
Modification of microstructures induced by temperature variation during irradiation with 14 MeV neutrons, *M. Matsuda, N. Yoshida, T. Muroga and M. Kiritani* 962
Effect of external tensile stress on the growth of interstitial loops, *H. Saka, K. Kawamura, Y. Morozumi and H. Teshima* 966
Evolution of structural damage in high-purity aluminum alloys during ion irradiation and the following heat treatments, *N. Kamigaki, S. Furuno, K. Hojou, K. Izui and T. Kino* 970
Depth distribution of damage in helium-ion and proton irradiated nickel, *T. Ezawa, M. Sugimoto, K. Niwase, S. Sasaki, A. Iwase, T. Iwata and F.E. Fujita* 974
Effect of hydrogen on the formation of interstitial loops in hydrogen-irradiated aluminum, *K. Ono, T. Kino, S. Furuno, K. Hojou, K. Izui, K. Mizuno and K. Ito* 978
Radiation hardening in neutron-irradiated polycrystalline copper: Barrier strength of defect clusters, *S. Kojima, S.J. Zinkle and H.L. Heinisch* 982
Computer simulation of early-stage irradiation creep, *J. Nagakawa, N. Yamamoto and H. Shiraishi* 986

6.4. Helium effects, bubbles and voids

Some limitations of simulation studies using the ppm to dpa ratio as the helium generation rate, *B.N. Singh and A.J.E. Foreman* 990
Microstructure and cavity swelling in reactor-irradiated dilute copper–boron alloy, *S.J. Zinkle, K. Farrell and H. Kanazawa* 994
Helium gas release due to grain boundary fracture in neutron-irradiated high-nickel austenitic alloys and a ferritic steel, *N. Kishimoto, R.E. Clausing, L. Heatherly, Jr. and K. Farrell* 998
In-situ observation of bubble formation in superconducting $YBa_2Cu_3O_{7-\delta}$ during He-ion irradiation in an electron microscope, *H. Maeta, S. Furuno, K. Hojou, H. Otsu and M. Watanabe* 1003
On the coarsening mechanisms of helium bubbles – Ostwald ripening versus migration and coalescence, *H. Schroeder and P.F.P. Fichtner* 1007
In-situ observation of the dynamic behavior of bubbles in aluminum during 10 keV H_2^+ ion irradiation and successive annealing, *S. Furuno, K. Hojou, H. Otsu, K. Izui, N. Kamigaki and T. Kino* 1011
Coprecipitation of $M_{23}C_6$ and MC type carbide under the influence of irradiation, *W. Kesternich and R.V. Nandedkar* 1015
Computer simulation of void swelling in metals and alloys, *E. Kuramoto* 1019

6.5. Phase stability and segregation

Stochastic description of compound stability under irradiation: Temperature, flux and cascade size effects, *F. Haider, P. Bellon, N.V. Doan and G. Martin* 1023
Enhanced diffusion of nickel in ion-irradiated FeNiB metallic glass, *A.K. Tyagi, M.-P. Macht and V. Naundorf* 1026
Microstructural stability in a Cu–Cr–Si alloy under 300 keV Cu^+ ion irradiation, *C. Ramachandra, N. Wanderka, R.P. Wahi and H. Wollenberger* 1030
Intergranular impurity segregation and embrittlement in neutron-irradiated iron alloys, *J. Kameda, X. Mao and A.J. Bevolo* 1034
The effect of helium atoms on radiation-induced segregation and precipitation in Al–Zn alloys, *T. Ezawa, J. Tanimura, T. Tanabe and F.E. Fujita* 1038
Irradiation induced diffusion and precipitate growth in ferritic Fe(Al,Ni), *J. Fischer and P. Jung* 1042
Irradiation-induced spinodal decomposition and its process in Fe–Mo alloys, *K. Nakai, C. Kinoshita and N. Nishimura* 1046
Inducement process and mechanism of spinodal decomposition in electron-irradiated Au–Ni alloys, *Y. Asai, Y. Isobe, K. Nakai, C. Kinoshita and K. Shinohara* . 1050
Effect of Xe-ion irradiation on austenitic stainless steel, *I. Sakamoto, N. Hayashi, B. Furubayashi and H. Tanoue* 1053
Effects of phosphorus, silicon and sulphur on microstructural evolution in austenitic stainless steels during electron irradiation, *K. Fukuya, S. Nakahigashi, S. Ozaki and S. Shima* 1057
Effects of neutron irradiation on corrosion and segregation behavior in austenitic stainless steels, *S. Nakahigashi, M. Kodama, K. Fukuya, S. Nishimura, S. Yamamoto, K. Saito and T. Saito* 1061

Radiation-induced segregation and high-temperature ductility in 12%CrMoVNb ferritic–martensitic steel, *N.C. Waite, G.J. Adetunji, R.G. Faulkner and E.A. Little* 1065

6.6. Damage mechanism and correlation

Determination of basic parameters for damage correlation, *H. Wollenberger and V. Naundorf* 1069
Comparison of PKA energy spectra, gas-atom production and damage energy deposition in neutron irradiation at various facilities, *R. Nishiguchi, Y. Shimomura, P.A. Hahn, M.W. Guinan and M. Kiritani* 1073
Microstructure–tensile property correlation of 316 SS in low-dose neutron irradiations, *N. Yoshida, H.L. Heinisch, T. Muroga, K. Araki and M. Kiritani* 1078
Mechanical property changes and microstructures of iron irradiated with fission and fusion neutrons, *A. Okada, T. Yasujima, T. Yoshiie, I. Ishida and M. Kiritani* 1083
Fusion–fission–light ion correlation of mechanical property change in a TZM alloy, *K. Abe, F. Nagase and S. Morozumi* 1088
Magnetic study of defects in iron induced by 14 MeV neutron irradiation, *S. Takehana, K. Hakozaki, M.W. Guinan and H. Matsui* 1092
The solute dependence of bias factors in irradiated Fe–Ni alloys, *J.J. Hoyt and F.A. Garner* 1096
Neutron irradiation test matrix for carbon-based materials for the first wall of fusion reactors, *K. Koizlik, J. Linke and H. Nickel* 1100
Fission reactor irradiation of materials with improved control of neutron flux–temperature history, *M. Kiritani, T. Endoh, K. Hamada, T. Yoshiie, A. Okada, S. Kojima, Y. Satoh and H. Kayano* 1104

Section 7. Engineering and Design, Database

Polymer composites as magnet materials: Irradiation effects and degradation mechanism of mechanical properties, *S. Egusa and T. Seguchi* 1111
Mechanical characteristics of the shape memory alloy driver focusing on quick replacement technology for fusion devices, *M. Nishikawa, M. Kawai, T. Yokoyama, T. Hoshiya, M. Naganuma, M. Kondo, K. Yoshikawa and K. Watanabe* 1115
Fast neutron irradiation of Ti–Ni shape memory alloys, *T. Hoshiya, S. Shimakawa, Y. Ichihashi, M. Nishikawa and K. Watanabe* 1119
Nuclear properties of magnet structural materials for fusion reactors, *M. Zucchetti, E. Medda and G. Maizza* 1123
Fusion neutron irradiation effects in commercial Nb_3Sn superconductors, *P.A. Hahn, M.W. Guinan, L.T. Summers, T. Okada and D.B. Smathers* 1127
The feasibility of welding irradiated materials, *H.T. Lin and B.A. Chin* 1131
Materials database for materials design, *S. Iwata, T. Ashino and S. Ishino* 1135
Development of an international fusion materials database, *J.W. Davis* 1139

Section 8. Irradiation Facilities

Characteristics of an energy selective neutron irradiation test facility (ESNIT) for material irradiation studies, *K. Noda, H. Matsuo, K. Watanabe, M. Sugimoto, Y. Kato, H. Sakai, T. Kikuchi, Y. Oyama, H. Ohno and T. Kondo* 1147
Production of transmutants and displacement effect in the EURAC spallation neutron source for testing of fusion materials, *J.M. Perlado, J. Sanz and M. Piera* 1151
Irradiation facilities development at CEA for solid and liquid breeder blankets qualification programs, *A. Alberman, F. Lefevre, G. Thevenot, M. Masson and M. Savineau* 1154
Irradiation facilities for testing solid and liquid blanket breeder materials with in-situ tritium release measurements in the HFR Petten, *R. Conrad and L. Debarberis* 1158

Discussion on Contributed Papers 1165

Section 9. Review on Design/Materials Interface for ITER

ITER: design overview, *K. Tomabechi for the ITER Team* 1173
Structural material requirements and related R and D for ITER plasma-facing components, *J.L. Boutard* 1179
ITER R&D on breeder blanket materials, *D.L. Smith, W. Daenner, G. Kalinin and H. Yoshida* 1185
ITER related R&D on low-Z plasma-facing materials for divertor and first wall, *M. Seki, M. Guseva, G. Vieider and J. Whitley* 1189
High-Z plasma-facing and related materials, *G.M. Kalinin* 1193

Section 10. Discussion Sessions

10.1. Cascade characteristics and defect production ... 1201
10.2. Materials aspects of breeding blanket design 1213
10.3. Criteria of low-activation and materials design .. 1221
10.4. Present limit and future direction of plasma-facing materials 1231
10.5. Design–material interface of ITER 1239
10.6. Irradiation correlation and need of intense high-energy neutron source 1245

Author index 1257

Subject index 1271